

TALK ABSTRACTS

Towards Stability Criteria for Rotating Superfluid Stars

Nils Andersson – *Southampton, UK*

In this talk I will describe a project aimed at deriving rigorous stability criteria for rotating superfluid stars. This involves a Lagrangian perturbation description of multifluid systems and the derivation of a canonical energy, which generalises that obtained by Friedman and Schutz for single fluids 25 years ago. Ultimately, we hope to derive criteria that establish whether a superfluid star is secularly unstable due to gravitational wave emission, and also whether dynamical instabilities (like the recently discovered superfluid two-stream instability) are present in the system. Partial results towards this ambitious final goal will be presented.

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Equation of Motion for Compact Binaries with Strong Internal Gravity

Hideki Asada – *Hirosaki, Japan*

We study the equation of motion for compact binaries in the post-Newtonian approximation by taking into account their strong internal gravity. Usual approaches need some regularization schemes in order to mediate divergent integrals coming from the point particle expressed as the delta function. Our approach assumes extended but compact objects. The equation of motion is obtained by performing surface integrals outside the bodies without any divergence, so that our result agrees with the previous works up to 2.5PN.

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The Explorer and Nautilus Gravitational Wave Detectors: Recent Results and Future Plans

Pia Astone – *Rome, Italy*

The two gravitational wave detectors Explorer (located at CERN) and Nautilus (in Frascati, LNF) have been operating for many years. These detectors allow to investigate various classes of signals, such as bursts, continuous waves, stochastic background. They operated in the year 2001 with unprecedented sensitivities, such to be sensitive to the conversion of 10^{-4} solar masses in the Galaxy into gravitational waves. I will present recent results, which regard in particular the search for continuous waves from the whole sky and the search for un-modelled bursts, and our plans for the immediate future.

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The Equation of State of Dense Matter: Where Do We Stand ?

O. Benhar – *Rome, Italy*

I will review the recent progress in the application of microscopic nuclear many-body theory to neutron star matter, and discuss the dependence of the predicted star observables upon the underlying dynamics.

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Asymptotic Black Hole Quasinormal Modes and the Area Quantum

Emanuele Berti – *Thessaloniki, Greece*

According to a recent proposal, a free parameter appearing in Loop Quantum Gravity can be fixed, using Bohr's correspondence principle, from a knowledge of highly-damped black hole oscillation frequencies. Such frequencies are rather difficult to compute, even for Schwarzschild black holes. However, it is now quite likely that they may provide a fundamental link between classical general relativity and quantum theories of gravity. We present a numerical computation of very highly damped quasinormal modes (QNM's) for charged and rotating black holes. In the Reissner-Nordström case QNM frequencies and damping times show an oscillatory behaviour as a function of charge, and the oscillations become faster as the mode order increases. This behaviour has been confirmed by analytical calculations. Kerr QNMs show a similar oscillating behaviour for $m=0$, while for $l=m=2$ they become asymptotically proportional to the angular velocity of the black hole horizon. We discuss possible implications of these results.

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Initial Data from a Non-conformal Decomposition of the Constraints

Nigel T. Bishop – *Pretoria, South Africa*

The usual procedure for setting initial data is to assume that the metric is conformal to some given metric, often the flat space metric. We have developed an alternative procedure based on a Kerr-Schild like ansatz. The method leads to a nonlinear elliptic equation. We will present solutions for the case of a perturbed Schwarzschild geometry, and also discuss progress towards using this method to obtain initial data for the two black hole problem.

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The Z4 formalism in Numerical Relativity

Carles Bona – *Palma, Spain*

The Z4 general-covariant formalism is presented with a view to Numerical Relativity applications. The hyperbolicity of the evolution system is studied both in the first and the second order versions. Standard numerical tests are performed showing the direct relationship between the well-posedness of the system and its performance of the numerical codes based on it.

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A constrained scheme for Einstein equations based on Dirac gauge and spherical coordinates: Application on slow evolution of bhs

Silvano Bonazzola – *Meudon, France*

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The LIGO Project: Status Report

Laura Cadonati – Boston, USA

The Laser Interferometer Gravitational-wave Observatory (LIGO) consists of three interferometers of km-scale length located in the United States (Livingston, LA and Hanford, WA). As the detector construction has been completed and its commissioning is well under way, LIGO has begun the acquisition of science quality data. The first science run (S1) occurred over two weeks in the summer of 2002. Its analysis yielded new upper limits for gravitational waves from various sources (bursts, binary inspirals, stochastic and - with GEO600 data - periodic sources). A second run (S2), with improved sensitivity, occurred over two months in the spring of 2003, and the LIGO Scientific Collaboration is now analysing the collected data. Concurrently, a tremendous effort is leading towards Advanced LIGO, which will add new technology to the existing detector infrastructure in order to suppress low frequency noise and improve the strain amplitude sensitivity by a factor of 10. This talk presents the current status of the LIGO detectors and their performance during the first two science runs, describes the data analysis techniques and results so far achieved, and reports on the status of the Advanced LIGO research and development.

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Improved Dynamics and Gravitational Waveforms from Relativistic Core Collapse Simulations

Pablo Cerda-Duran – Valencia, Spain

We present results from hydrodynamical simulations of rotational core collapse using an axisymmetric general relativistic code. The code evolves the coupled system of metric and fluid equations using the ADM 3+1 formalism, and a new approach for the metric equations which we call CFC+. In this approach we add new degrees of freedom to the original conformally flat metric approximation (CFC) of Isenberg-Wilson-Mathews, to extend it to second post-Newtonian order. The metric equations are still elliptic, but the number of equations is significantly augmented in comparison to the original CFC approach. The hydrodynamics and the CFC metric evolution is calculated using the code developed by Dimmelmeier et al. (2002). Correspondingly the corrections for CFC+ are computed solving a system of elliptic linear equations. Initial models are differentially rotating relativistic 4/3-polytropes in equilibrium with central density of $10^{10} \text{ g cm}^{-3}$. The collapse is initiated by slightly reducing the adiabatic index. Gravitational wave signals for a comprehensive sample of collapse models are extracted using the quadrupole formula. We discuss our results on the dynamics and the gravitational wave emission from Newtonian, CFC and CFC+ simulations.

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The “Dual” Gravitational Waves Detector

Massimo Cerdonio – Padua, Italia

The advanced “dual” acoustic detectors is a “third kind” of gravitational waves detector: while interferometers work wideband far from and “single” bars and spheres work narrowband at system resonant modes, the “dual” works wideband in between gw sensitive resonant modes of the system, thanks to an additive effect on signal and a subtraction effect on back action. The “dual” would be very sensitive at kHz frequencies. We would investigate, with a direct probe, the dynamics of matter at extreme densities in fully relativistic stars, in particular: Sn core collapses, ns “bar” instabilities, ns fragmentation, merging of ns and bh, bh ringdown, quasi-normal modes of ns, rotational instabilities in ns, neutron fluid shock waves in newborn hot ns, long duration chirps from g-bursts. The “dual” would also complement the “advanced” interferometers of the 2010 timeframe in searches of poor signature high frequency signals as: the final phase of inspiraling bh-bh, bh-ns!

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Inferences from Simultaneous Observation of Electromagnetic and Gravitational Waves from Coalescing Compact Bodies

Sandip Chakrabarti – *Kolkata, India*

It is now well known that angular momentum distribution in accretion flows must deviate from that of a Keplerian distribution. This means that a coalescing compact object instantaneously on a Keplerian orbit must exchange angular momentum with the accretion flows. The gravitational wave signal of the merger of a small compact with a massive black hole at the galactic center would then be modified due to the presence of the disk. This is quantified using various accretion flow parameters. At the same time, the same parameters also quantifies electromagnetic spectrum coming out of the disk. We discuss the possibility of extraction of system parameters from such observations.

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Unveiling Binary Black Holes in Globular Clusters

Monica Colpi – *Milan, Italy*

Globular clusters should hide in their cores many black holes born from the most massive stars. However, it is suspected that only a few remain in the cluster, as they tend to segregate in the core driven by a mass segregation instability. In the core, close dynamical encounters become important. Binary black holes thus form that interact with other black holes. As a result of these super-elastic encounters, over a few billion years, most of the black holes are ejected from the parent cluster. Only one or a few remain, the heaviest preferentially bound in a binary. The binaries ejected are hard enough to become important sources of gravitational waves. The one that remains in the cluster could instead become an important dynamical perturber on stars passing by. Unveiling a black hole binary in the center of a globular cluster is thus an observational challenge as it may provide clues on scenarios of formation and evolution. The globular cluster NGC 6752 seems the preferred candidate for this search. NGC6752 hosts in its halo PSR J1911-5958A, a newly discovered binary millisecond pulsar which is the most distant pulsar ever known from the core of a globular cluster. Its recycling history seems in severe conflict with a scenario of ejection resulting from ordinary stellar dynamical encounters. In this paper, we conjecture that a binary of two black holes with masses in the range between 10 and 50 solar masses could provide, in a 4-body scattering event, the necessary thrust to propell PSR J1911-5958A into its current peripheral orbit. We report results on a series of 4-body scattering experiments that support this scenario and discuss the potential impact of this discovery.

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Do Neutron Star Gravitational Waves Carry Superfluid Imprints?

Gregory Lee Comer – *St. Louis, USA*

Isolated neutron stars undergoing non-radial oscillations are expected to emit gravitational waves in the kilohertz frequency range. To date, radio astronomers have located more than 1,400 pulsars, and can estimate that there are about 2×10^8 neutron stars in the galaxy. Most of these are surely old and cold enough that their interiors will contain matter in superfluid or superconducting states. In fact, the glitch phenomenon in pulsars (a sudden spin-up of the pulsar's crust) is best described by assuming the presence of superfluid neutrons and superconducting protons in the inner crusts and cores of the pulsars. Recently there has been much progress on modelling the dynamics of superfluid neutron stars in both the Newtonian and general relativistic regimes. We will discuss some of the main results of this recent work; in particular, it will be argued that superfluidity should affect the gravitational waves from neutron stars (emitted, for instance, during a glitch) by modifying both the rotational properties of the background star and the modes of oscillation of the perturbed configuration. For example, two-fluid models of neutron star superfluidity yield a mode-spectrum for non-rotating backgrounds that contains a new set of so-called superfluid modes, which are predominately acoustic in nature, but no g-modes.

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Finding Event Horizons in Numerical Spacetimes

Peter Diener – *Potsdam, Germany*

I will present a new event horizon finder for 3D numerical spacetimes. Because a level set description of the surface is used, changes of topology can be handled naturally even in spacetimes with no inherent symmetries. Some preliminary results on the physics of event horizons in very dynamic spacetimes will also be presented.

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Gravitational Waves from Supernova Core Collapse: Present Status and Future Developments

Harald Dimmelmeier – *Garching, Germany*

In the last years, there has been considerable progress in numerical simulations of supernova core collapse. One of the key objectives of this field of research is to predict gravitational wave signals emitted by such events for the use as wave templates in the data analysis of gravitational wave detectors. In this talk I present an overview of important existing work and promising new approaches on core collapse simulations, with a particular focus on gravitational wave signals recently obtained by us. I also address the issue of robustness of our results and discuss the usefulness of our wave templates for data analysis. Additionally, I want to point out new numerical approaches and future directions in this field of research.

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A Light-cone Approach to Axisymmetric Stellar Core Collapse

Toni Font-Roda – *Valencia, Spain*

The talk discusses axisymmetric stellar core collapse simulations in general relativity. We have developed a hydrodynamics code which has proved robust and accurate enough to allow for a detailed analysis of the global dynamics of the collapse. Contrary to traditional approaches based on the 3+1 formulation of the gravitational field equations, our framework uses a spacetime foliation based on a family of outgoing light cones, emanating from a regular center, and terminating at future null infinity. Such a coordinate system is well adapted to the study of interesting dynamical spacetimes in relativistic astrophysics such as stellar core collapse and neutron star formation. Perhaps most importantly this procedure allows for the unambiguous extraction of gravitational waves at future null infinity without any approximation, along with the commonly used quadrupole formalism for the gravitational wave extraction. Our results concerning the gravitational wave signals show noticeable disagreement when those are extracted either computing the Bondi news at future null infinity or using the quadrupole formula. We have strong indication that the quadrupole formula in the form applied in our code does not lead to physical gravitational wave signals. The Bondi gravitational wave signals extracted at infinity show typical oscillation frequencies of about 0.5 kHz.

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Stellar Dynamics Working for LISA: Stars Captured by a Massive Black Hole

Marc Freitag – *Heidelberg, Germany*

Among the astrophysical systems targeted by LISA, stars on relativistic orbits around massive black holes (MBHs) are particularly promising sources. From the gravitational signal emitted by the stars as they spiral in, precise information about the mass and spin of MBHs can be obtained. However, the prediction for the number and characteristics of such sources suffer from many uncertainties. Stellar dynamical Monte Carlo simulations of the evolution of galactic nucleus models allow more realistic estimates of these quantities and an exploration of their dependencies on the model's parameters. Furthermore, they strongly suggest that the closest such extreme mass-ratio binary to be detected by LISA could be a MS star orbiting the MBH at the centre of our Milky Way.

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Spacetime Modes of Rotating Compact Stars

Kostas Glampedakis – *Cardiff, UK*

We study the spacetime quasi-normal modes (w-modes) of a relativistic, uniform density, rotating compact star. This is achieved by assuming the star to be slowly rotating and by performing direct mode calculations in the frequency domain supplemented by time evolutions of scalar field perturbations. Our results suggest that rotation plays a significant role in the properties of w-modes of ultra and moderately compact stars while being less important for stars of low compactness. In particular, modes associated with an azimuthal integer index $m < 0$ become longer-lived or even unstable (a manifestation of the so-called ergoregion instability) with increasing rotation and for given compactness. The actual excitation and observability of such modes is discussed.

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Families of Initial Data for Binary Black Holes

Philippe Grandclement – *Evanston IL, USA*

Amongst the numerous challenges that theorists face at the dawn of gravitational astronomy, the simulation of the coalescence of binary black holes is one of the more exciting. Indeed, not only is it a system that will fully test the strong-field regime of General Relativity but is also one of the most anticipated source for the first generation of interferometric detectors. Numerical simulations of binary black holes rely, almost exclusively, on the 3+1 formulation of Einstein's equations. When using such a formalism, one must first precise a set of initial data that is then evolved to get the solution at later times. If it is difficult to get stable evolutions for long periods of time, it is equally difficult to determine initial data that represent realistic configurations of two black holes. Indeed, if it is relatively easy to compute solutions of the constraint equations, it is much more difficult to do it in a way that imposes a well known physical content to the initial data. In this talk, I will try to give a review on the initial data problem. Starting from the early work on this subject by Misner, Lindquist and Brill, I will present some of the principal methods used to generate initial data for evolutionary codes. In particular, I will show how those methods give results in disagreement with the ones given by post-Newtonian. I will then present a new method, developed by the Meudon group, that, by imposing the existence of a Killing vector, gives, for the first time, results in good agreement with the post-Newtonian ones. I will conclude by exposing the improvement still to be made in order to get astrophysically relevant initial data for binary black holes.

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Neutrino-transport Effects on Proto-Neutron Star Oscillations, and on GW Emission Frequencies

Leonardo Gualtieri – *Rome, Italy*

We develop the equations of relativistic non-radial perturbations of a star, to include consistently heat transport effects that are especially significant for newly born proto-neutron stars, due to neutrino transport. We show that, including these effects, the frequencies of the quasi-normal modes acquire a larger imaginary part, of the order of the inverse dissipation timescale.

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Computing gravitational waves from slightly nonspherical stellar collapse: Odd-parity perturbation

Tomohiro Harada – *London, UK*

We numerically study gravitational waves from slightly nonspherical stellar collapse to a black hole in the linearized Einstein theory in which we adopt a spherically collapsing star to a black hole as the zeroth-order solution and gravitational waves are computed in the perturbation theory on the spherical background. Here, we focus on the perturbation of odd-parity modes. Using the polytropic equations of state with the polytropic indices n_p as $n_p = 1$ and 3 , we qualitatively study gravitational waves emitted during the collapse of neutron stars and supermassive stars to black holes. For $n_p = 1$, the gravitational waveforms are mainly characterized by a black-hole quasinormal mode ringing irrespective of the perturbation profiles initially given. However, for $n_p = 3$, the waveforms depend strongly on the perturbation profiles initially given.

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Dynamics of neutron star collapse to a black hole

Ian Hawke – *Potsdam, Germany*

Neutron stars are expected to occur as the end states of many astrophysical processes, including core-collapse supernovae and the merger of binary stars. Instabilities in neutron stars can occur in a number of ways, including through accretion or some change in the pressure support through phase changes or cooling. The neutron star may then collapse to a black hole. Here we perform fully relativistic 3D numerical simulations of the collapse using the EU Network hydro code. Particular attention is paid to the late stage of the collapse and the dynamics of the apparent and event horizons that form.

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Search for Gravitational Wave Events and Data Quality Evaluation on TAMA300

Nobuyuki Kanda – *Osaka, Japan*

TAMA300 is laser interferometric gravitational wave detector in Japan. The project started at 1995, and have been developed the its sensitivity (noise level) and stability for the observatory of the gravitational wave from cosmic sources. Since 1999 summer, we had eight times of major data taking with our detector. A total amount of data exceed 2300 hours currently. We think that TAMA opened the new phase of the operation as a gravitational wave observatory. In this conference application, we will display not only for TAMA's detector status, but also strongly focusing on the latest results of data analysis of TAMA300, which include issues for gravitational wave events search and quality evaluation from the view of the event search analysis. Promised target of gravitational wave source is neutron stars (or black holes) binary coalescence. We established matched filter analysis with inspiral waveform of coalescence. Also with the assumption of black hole quasi-normal mode, we are searching for ringdown gravitational wave. Upper limits of these searches will be displayed in the talk.

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Dynamical Instability of Differentially Rotating Polytropes

Shigeyuki Karino – *Tokyo, Japan*

We have studied the behavior of $m=2$ f -mode (bar-mode) oscillations in differentially rotating polytropes by using linear stability analysis method. Classically, it is well known that a rigidly rotating star with uniform density becomes unstable against bar-mode when the stellar rotation rate is sufficiently high, as $T/|W| > 0.27$. Here, T and W are the rotational energy and the gravitational potential energy, respectively. However, we found that the critical rotation rates where the dynamical instability of bar-mode occurs will decrease significantly, as the degree of differential rotation becomes higher. When we consider strong differential rotations, the mode will be unstable even if $T/|W|$ is much less than 0.27. Also it is found that this tendency is almost independent from the polytropic index. Additionally we will introduce a new result that when we consider extremely strong differential rotations, at least one unstable mode will exist even if $T/|W| < 0.14$. The detailed property of such an unstable mode is still unknown, but it may be the same instability which has been found by recent non-linear simulations (Shibata et al. 2002, 2003). Such slow rotation instabilities of compact stars can be detectable sources of gravitational waves.

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Estimation of Binary Pulsar Coalescence Rates and Detection Rates for Gravitational Wave Detectors

Chunglee Kim – *Evanston IL, USA*

Inspiraling binary pulsar systems are one of the most promising gravitational wave sources to be detectable by gravitational-wave detectors. The detection rates for ground-based detectors (e.g. LIGO, GEO600, VIRGO, and TAMA) or the future space-based one (e.g. LISA) can be inferred by the coalescence rate for these systems. We will present a newly developed statistical analysis method to estimate the Galactic coalescence rate, R , of pulsar binaries and the detection rate of these systems by LIGO or LISA. The method involves the simulation of selection effects inherent in all relevant radio pulsar surveys and a Bayesian analysis to calculate the probability distribution of R . One of the advantages of this method is that it can be applied to any type of pulsar population. Results for neutron star-neutron star and neutron star-white dwarf binaries will be presented. We will also discuss the statistical significance of each estimated value as well as the correlation between model parameters and R for both cases.

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Probing Compact Stars with Gravitational Waves

Yasufumi Kojima – *Hiroshima, Japan*

Gravitational waves emitted from stars have important information about the sources. Using perturbed Einstein equations, we show how the interior structure affects the characteristic frequencies and damping times of the radiation.

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High Frequency Gravitational Wave Astronomy

Kostas Kokkotas – *Thessaloniki, Greece*

Sources of high frequency gravitational waves are reviewed. Gravitational collapse, rotational instabilities and oscillations of the remnant compact objects are potentially important sources of gravitational waves. Significant and unique information for the various stages of the collapse, the evolution of proto-neutron stars and the details of the equations of state of such objects can be drawn from careful study of the gravitational wave signal.

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Dirty Binary Black Hole Evolutions

Pablo Laguna – *University Park PA, USA*

Reaching the ultimate goal of simulating binary black hole systems, with enough accuracy and dynamical range to be relevant to observations, requires careful development and implementation of infrastructure to handle all aspects of the problem. Gauge conditions, initial data, boundary conditions, black hole singularities, evolution equations, constraint preservation and numerical approximations are a few examples. At the same time, insight also can be obtained by following a “quick and dirty” approach in which some elements of the problem are simplified or approximated. We present results of binary black hole evolutions following this approach. The quality of these results are limited, but they provide valuable information for future, cleaner calculations.

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Background-independent Gravitational Waves in Post-Minkowskian Spacetimes

Luca Lusanna – *Florence, Italy*

A Hamiltonian linearization of the rest-frame instant form of tetrad gravity, where the Hamiltonian is the weak ADM energy, in a completely fixed (non-harmonic) 3-orthogonal Hamiltonian gauge is defined. All the geometrical quantities, lapse and shift functions included, are expressed in terms of the two canonical pairs of Dirac observables describing the independent degrees of freedom of the gravitational field in this gauge and replacing the two polarizations of the harmonic TT gauge. For the first time the canonical reduction allows to find an explicit solution of all the Hamiltonian constraints and an associated linearized solution of Einstein's equations. It corresponds to background-independent gravitational waves in a well defined post-Minkowskian Christodoulou-Klainermann spacetime. Preliminary results are given for tetrad gravity plus a perfect fluid, in a fully relativistic way without any post-Newtonian approximation. A post-Minkowskian approximation (formal perturbative expansion in the Newton constant) should allow to define a well-posed Hamiltonian numerical gravity.

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First Order Gravitational Radiation Reaction of a System of Compact Objects

Oswaldo Moreschi – *Cordoba, Argentina*

We study the dynamical equations for a binary system of compact objects arising from the asymptotic structure of the corresponding isolated system. We make use of the center of mass frame at future null infinity and keep terms up to first order of gravitational radiation.

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General Relativistic Numerical Simulation on Coalescing Binary Neutron Stars

Ken-ichi Oohara – *Niigata, Japan*

We are developing 3 dimensional simulation codes for coalescing binary neutron stars. A stable code using maximal slicing condition is obtained. To evaluate the gravitational radiation, we implemented a gauge-invariant wave extraction and compared the wave forms with a simple estimate of waves from metric perturbation. The energy spectrum of the waves was also evaluated to investigate the possibility that the excitation of the quasi-normal modes of black hole, which may be formed after merger of two stars, can be caught.

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Some Issues about Proto-Neutron Stars: Do They Pulsate and Rotate as "Standard" Neutron Stars ?

Jose Pons – *Valencia, Spain*

In many senses, newly born neutron stars are quite different to old NSs. In particular, two open issues that remain unclear are: How fast and how rigidly do they rotate ? and Do we expect that the quasi-normal modes be excited following the bounce in the standard Supernova mechanism ? I discuss several possibilities that might change the picture substantially, what are we doing to improve and what should be done next.

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The Virgo Detector: Status Report

Piero Rapagnani – *Rome, Italia*

The French-Italian collaboration Virgo was born in 1989 between eleven groups of CNRS (France) and INFN (Italy) with the aim to build a large interferometric detector for gravitational waves in Italy. In 1994, the site of the laboratory was chosen: the plain of Cascina, near Pisa. Construction started in 1996 and ended in July 2003, when the last mirror of the interferometer was put in position at the end of the west arm. The detector is essentially a Michelson interferometer which measures the relative motion of two test masses 3 km apart, with a sensitivity of $h = 10^{-23}$ from 10 Hz to 5 kHz. Currently, the commissioning of the apparatus has started: by March 2004 Virgo should produce the first scientific data. We shall report the current status of the experiment, and discuss its expected sensitivity for several kind of sources.

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Novel Finite-Differencing Techniques for Numerical Relativity: Application to Black Hole Excision

Oscar Reula – *Cordoba, Argentina*

We use rigorous techniques from numerical analysis of hyperbolic equations in bounded domains to construct stable finite-difference schemes for Numerical Relativity, in particular for their use in black hole excision. As an application, we present 3D simulations of a scalar field propagating in a Schwarzschild black hole background.

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Gravitational Waves from Binary Neutron Stars

Dorota Gondek-Rosinska – *Meudon, France*

Inspiraling neutron (strange quark) star binaries are expected to be among the strongest sources of gravitational radiation. We study equilibrium sequences of close binary systems composed of neutron stars described by realistic equation of states (e.g Akmal et al.1998). The solving method is a multi-domain spectral method. Calculations are performed in general relativity.

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Collapse of a Differentially Rotating Supermassive Star

Motoyuki Saijo – *Kyoto, Japan*

We investigate the gravitational collapse of a rapidly rotating relativistic star by means of a 3+1 hydrodynamical simulations in conformally flat spacetime of general relativity. We evolve a differentially rotating star of $q = J/M^2 \sim 1$ (J is the total angular momentum and M is the total gravitational mass energy of the star) from $R/M \sim 70$ (R is the circumferential radius of the star) to the point where conformally flat approximation breaks down. We shrink the computational domain several times to maintain the central grid resolution to focus on the final outcome of the collapse. We preliminary find in our model that the star cannot collapse but bounce when $q > 1.1$ due to the centrifugal force of the star. On the other hand, the collapsing star is likely to form a black hole coherently when $q < 0.95$. We discuss the final outcome of the radial unstable star collapse of $q \sim 1$, and also discuss whether the collapsing star will be a promising source of gravitational waves.

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Searching for binaries in interferometer data: Current status and future prospects

B. S. Sathyaprakash – Cardiff, UK

In this talk I will cover the various approaches that have been followed to search for signals from inspiralling and merging black holes and neutron stars. I will begin with an overview of the basic data analysis problem and then go on to describe the difficulties encountered in a real data analysis exercise. I will conclude by discussing recent results reported in the literature on the analysis of data from LIGO and GEO detectors.

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Three Years of Gravitational Wave Research in Europe

Ed Seidel – Potsdam, Germany

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Gravitational Wave Cosmology Around 1Hz

Naoki Seto – Pasadena CA, USA

We might open a deep window of gravitational waves around 1Hz, as this band might not be seriously contaminated by binary confusion noise, comparing to lower frequencies, e.g. LISA band. Here there are various possibilities of doing cosmology using gravitational wave antennas in this band. Stochastic wave background from very early universe is one of the most interesting targets. By analyzing the background we could obtain interesting information of inflation or state of universe at later epoch $T \sim 10^6$ GeV. For detection of the weak background we need to remove contributions of cosmological NS+NS, BH+NS or BH+BH binaries accurately from data streams of detectors. But these systems are very accurately clocks distributed within horizon. We show that the acceleration of the universe could be directly measured by observing chirping gravitational waves from these systems for several years.

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Nonlinear Generation of Harmonics in Highly Distorted Black Holes

Deirdre M. Shoemaker – Ithaca NY, USA

Simulations of highly distorted black holes provide us with a suitable system to investigate the generation of nonlinear harmonics in black-hole oscillations. We conduct numerical experiments of the scattering of a large amplitude perturbation incident on a black hole in order to investigate the harmonic content of the scattered wave. Papapadopoulos (2002) found that nonlinear coupling is inefficient in channeling energy away from the dominant mode. We expand on this work by studying the scattered wave's dependence on the azimuthal quantum number, m , and the effects of larger amplitude waves. This experiment has direct implications to data analysis efforts by making it possible to estimate the family of modes relevant to the design of software detection tools.

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Searching for Continuous GW Signals

A. Sintes – *Palma, Spain*

Continuous gravitational waves from rotating neutron stars are among the most promising sources for ground based interferometer detectors. The fact that we can monitor the rotation rate of pulsars with other astronomical instruments makes them particularly interesting targets for gravitational waves detectors. Although young rapidly rotating neutron stars are probably better initial candidates for GW detection than the known set of radio pulsars, the data analysis problem for these putative sources is greater because of their unknown location and frequency evolution. Since the expected gravitational wave amplitude from pulsars is very weak it is necessary to integrate the data for long periods of time (months to year) with the signal-to-noise ratio increasing roughly as the square root of the observing time. Several data analysis techniques have been used, and others are under development, able to handle efficiently these long stretches of data.

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Equilibrium and Pulsations of Differentially Rotating Neutron Stars

Nikolaos Stergioulas – *Thessaloniki, Greece*

We construct evolutionary sequences of differentially rotating neutron stars and study their axisymmetric pulsations in the Cowling approximation. We focus on the low-order quasi-radial and quadrupole modes which are excited during rotational core-collapse. At large rotation rates the pulsations are trapped in a narrow region around the equatorial plane, due to wave-trapping by the centrifugal force. The mode-frequencies are considerably smaller than the corresponding frequencies in a nonrotating model of same baryonic mass. We show that near the mass-shedding limit of the equilibrium star, nonlinear pulsations are strongly damped by mass-shedding in the equatorial plane. This damping effect is also relevant for the gravitational-wave-induced nonaxisymmetric f -modes and r -modes.

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A Fast Apparent-Horizon Finder for 3-Dimensional Cartesian Grids in Numerical Relativity

Jonathan Thornburg – *Potsdam, Germany*

In 3+1 numerical simulations of dynamic black hole spacetimes, it's useful to be able to find the apparent horizon(s) (AH) in each slice of a time evolution. A number of AH finders are available, but they often take many minutes to run, so they're too slow to be practically usable at each time step. Here I present a new AH finder, *AHFinderDirect*, which is very fast and accurate: at typical resolutions it takes only a few seconds to find an AH to $\sim 10^{-5}$ accuracy on a GHz-class processor. I assume that an AH to be searched for is a Strahlkoerper (star-shaped region) with respect to some local origin, and so parameterize the AH shape by $r = h(\text{angle})$ for some single-valued function $h : S^2 \rightarrow R_+$. The AH equation then becomes a nonlinear elliptic PDE in h on S^2 , whose coefficients are algebraic functions of g_{ij} , K_{ij} , and the Cartesian-coordinate spatial derivatives of g_{ij} . I discretize S^2 using 6 angular patches (one each in the neighborhood of the +- x, +- y, and +- z axes) to avoid coordinate singularities, and finite difference the AH equation in the angular coordinates using 4th-order finite differencing. I solve the resulting system of nonlinear algebraic equations (for h at the angular grid points) by Newton's method, using a "symbolic differentiation" technique to compute the Jacobian matrix. *AHFinderDirect* is implemented as a thorn in the Cactus computational toolkit, and is freely available by anonymous CVS checkout.

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Gauge Conditions for Binary Black Hole Puncture Data Based on an Approximate Helical Killing Vector

Wolfgang Tichy – *University Park PA, USA*

To date most gravitational wave forms obtained from numerical binary black hole simulations are based on puncture initial data. We show that puncture data for quasicircular binary black hole orbits allow a special gauge choice that realizes some of the necessary conditions for the existence of an approximate helical Killing vector field. Introducing free parameters for the lapse at the punctures we can satisfy the condition that the Komar and ADM mass agree at spatial infinity. Several other conditions for an approximate Killing vector are then automatically satisfied, and the 3-metric evolves on a timescale smaller than the orbital timescale. The time derivative of the extrinsic curvature however remains significant. Nevertheless, quasicircular puncture data are not as far from possessing a helical Killing vector as one might have expected.

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Equilibrium Solutions of Binary Neutron Stars in Quasi-Circular Orbit

Kōji Uryū – *Trieste, Italy*

Numerical solution for binary neutron stars in circular orbit provides a model for the final stage of inspiral as a result of gravitational wave emission. Methods to compute such equilibriums so far have solved a reduced set of Einstein equations under assuming conformal flat 3-geometry. Our new methods treat more generic space-time under helical symmetry, or employ the waveless approximation, which are governed by all components of Einstein equations being solved consistently. Among the various types of waveless approximations, we employed a way in which the time derivatives of the spatial part of the conformally rescaled metric is dropped in non-rotating frame under taking gauge conditions which are the maximal slicing condition, and the spatial divergence free condition for conformally rescaled spatial metric. Applying the helical symmetry to the matter equations, solutions for irrotational binary neutron stars in quasi-equilibrium circular orbit is computed. These solutions enable us to model an intermediate phase of inspiraling between post-Newtonian method being valid and a binary merger accurately. The generic treatment of metric may reduce spurious error which is introduced from initial data to the beginning of merger simulations and hence improve accuracy and reliability of the result.

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The LISA Detector: Status Report

Stefano Vitale – *Trento, Italy*

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The Dynamics of Differentially Rotating Neutron Stars

Anna Watts – Southampton, UK

Differential rotation, where different parts of a neutron star rotate with different angular velocities, can develop in several ways. These include the supernova in which the stars are born, non-linear effects associated with stellar vibrations, and rapid accretion. The collision of two neutron stars can also give rise to a long-lived differentially rotating remnant. Understanding the effects of differential rotation is critical, because it is after violent events like the supernova or a collision that we expect strong vibrations and gravitational wave emission. Differential rotation can dramatically alter the way in which a neutron star vibrates, introducing dynamical shear instabilities, and a continuous spectrum that is physically distinct from the discrete stable oscillation frequencies of a uniformly rotating star. I will discuss the type of vibrations that occur, their impact on the stability of the star, and the potential effects on gravitational wave emission.

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POSTER ABSTRACTS

On Binary Neutron Stars with Non Conformally Flat Metric

Francois Limousin – *Meudon, France*

I would present my work on binary neutron stars with a general 3-metric. I keep the assumption of an helicoidal Killing vector but I don't use the IWM approximation so I solve the ten Einstein's equations. I use LORENE for the numerical implementation. I would show the numerical algorithm and the first results of this study.

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Strongest Gravitational Waves from Neutrino Oscillations at Supernova Core Bounce

Herman Julio Mosquera Cuesta – *Rio de Janeiro, Brasil*

Resonant active-to-active ($\nu_a \rightarrow \nu_a$), as well as active-to-sterile ($\nu_a \rightarrow \nu_s$) neutrino (ν) oscillations can take place during the core bounce of a supernova collapse. Weak magnetism increases antineutrino ($\bar{\nu}$) mean free paths, and thus its luminosity. Because the oscillation feeds mass-energy into (or takes it out of) the target ν species, the large mass-squared difference between species ($\nu_a \rightarrow \nu_s$) implies a huge amount of energy to be given off as gravitational waves ($L_{\text{GWS}} \sim 4 \times 10^{49} \text{ erg s}^{-1}$) due to anisotropic ν flow over the oscillation length, driven by both spin-magnetic and the universal spin-rotation coupling. The novel contribution of this paper stems from the use of the tight constraints from neutrino experiments as SNO and KamLAND, and the cosmic probe WMAP, to recompute the gravitational-wave emission during neutrino oscillations in supernovae core collapse and bounce. The new spacetime strain thus estimated is still several orders of magnitude larger than those from ν diffusion (convection and cooling) or quadrupole moments of neutron star matter. This new feature turns these bursts the more promising supernova gravitational-wave signal detectable by observatories as LIGO, VIRGO, etc., for distances far out to the VIRGO cluster of galaxies.

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Rapidly Rotating Relativistic Stars as Sources of Gravitational Waves

Dorota Gondek-Rosinska – *Meudon, France*

*The laser interferometric gravitational wave detectors should be fully operationally soon. Triaxial instabilities of rotating relativistic stars can play an important role as an emission mechanism of gravitational waves in the frequency range of forthcoming LIGO/VIRGO interferometric detectors. We study the secular triaxial instability of rigidly rotating neutron stars and strange quark stars in general relativity. At the Newtonian limit, this corresponds to the bifurcation point between the Maclaurin spheroid and the Jacobi ellipsoids. We find that general relativity weakens the instability, but stabilizing effect is not very strong. Contrary to neutron stars, strange stars with $T/|W|$ (the ratio of the rotational kinetic energy to the absolute value of the gravitational potential energy) much lower than the corresponding value for the mass-shed limit can be secularly unstable to the bar mode formation if shear viscosity is high enough to damp out any deviation from uniform rotation. The instability develops for a broad range of gravitational masses and rotational frequencies of strange quark stars. It imposes strong constrain on lower limit on the frequency at innermost stable circular orbit around rapidly rotating strange stars. Above results are robust for all linear self-bound equation of state assuming the growth time of the instability being faster than the damping timescale. Whether the instability can grow or not it depends on many different physical mechanism (e.g. value of viscosities (rather uncertain)). We discuss astrophysical scenarios when triaxial instabilities (*r*-mode and viscosity driven instability) could be relevant (a newly born star, an old star spinning up by accretion) in strange stars described by the standard MIT bag model of normal quark matter. We show that the spin evolution of strange stars strongly depend on the strange quark mass.*

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The Expected Mass Ratio of Compact Object Binaries Observed with Gravitational Waves

Dorota Gondek-Rosinska – *Meudon, France*

We use the *StarTrack* binary population synthesis code to analyze the distribution of mass ratios of compact object binaries. We consider three separate groups: the double neutron star binaries; the black hole neutron star binaries, and the double black hole binaries. We first consider the intrinsic distribution of mass ratios for these three groups, and then we calculate the detectability weighted distributions. We discuss the dependence of the results on the assumed stellar evolutionary model.

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Influence of potential Quark Matter in Neutron Stars on Gravitational Waves in Neutron Star Mergers

Roland Oechslin – *Garching, Germany*

We consider the influence of potential quark matter existing at high densities in neutron stars on gravitational waves (GW) emitted in a binary neutron star merger event. Using two different equations of state (EoS), one including a transition to a hadron-quark phase transition the other without, we perform hydrodynamical simulations of this event. We also calculate binary equilibrium sequences around the innermost stable orbit (ISCO) to determine the gravitational wave frequencies at that point. The hydrodynamical simulations are based on the conformally flat (CF) approximation to general relativity and the GW signal is extracted to quadrupole order. Depending on the EoS, we determine the characteristic GW frequencies at the ISCO and, if possible, that of the merger remnant.

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Gravitational Waves from White Dwarfs

Avetis Abel Sadoyan – *Yerevan, Armenia*

The rotating White Dwarfs can be important sources of gravitational waves with frequencies close to 1Hz. The Galactic population of these sources may prove to be a confusion limited foreground for proposed advanced detectors in the frequency band between space-based and ground based interferometers. We present the estimated parameters of Gravitational Waves from a number of White Dwarfs. As in the range 100pc from the Earth there are several thousands of White Dwarfs, then their input to the gravitational wave noise in the frequency range around 1Hz will be significant and should be taken into account in construction of new detectors for Gravitational Waves.

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Radiation Reaction in Capture of Stars by Black Holes

Alessandro D.A.M. Spallicci – *Nice, France*

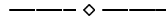
The radial fall motion of a test particle is examined up to radiation reaction terms. The Regge-Wheeler-Zerilli-Moncrief wave equation for even perturbation is solved numerically for the perturbation components appearing in the geodesic equation.

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Bound Null Geodesics in Extremely Compact Stars

Zdeněk Stuchlík – *Opava, Czech Republic*

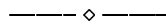
In extremely compact stars with radius $R < 3M$, bound null geodesics should exist around the stable circular null geodesic. Therefore, bound neutrinos or gravitational waves could be trapped by the extremely compact stars influencing substantially its state. Assuming the simplest model of spherically symmetric stars with uniform distribution of energy density but radius-dependent pressure, we give an estimation of the trapping process on the neutrinos uniformly and isotropically radiated inside of such star. It is shown that up to 1/2 of the flow of emitted particles can be trapped in the stars with radius $R < 2.5M$. For a realistic radius about $2.93M$, the flow of emitted neutrinos could be trapped. The existence of a relevant number of neutrinos trapped in the external parts of extremely compact stars implies a 'two-temperature' process of cooling of such stars.



General Relativistic Polytropes with a Nonzero Cosmological Constant

Zdeněk Stuchlík – *Opava, Czech Republic*

The quantum string cosmology elaborated by J. Ellis, N. Mavromatos and D. Nanopoulos predicts a repulsive cosmological 'constant', or vacuum energy, inversely proportional to the cosmological scale factor. The repulsive effects of such vacuum energy have to be very strong in the early stages of the universe. Therefore, we shall study the role of a repulsive cosmological constant on the spherically symmetric, static configurations of perfect fluid obeying a polytropic equation of state. The static equilibrium configurations are determined by two coupled first-order nonlinear differential equations that are solved by numerical methods. The configurations are specified in terms of three parameters – the polytropic index n , the central pressure to central energy density of matter ratio σ , and vacuum energy density to central density of matter ratio λ . The polytropes are represented by radial profiles of energy density, pressure, mass, and metric coefficients. The mass-radius relation of polytropes is characterized by a parameter called compactness C , and extremely compact polytropes with $C < 3$ containing regions of trapped null geodesics are given. The geometry of the polytropes is conveniently represented by embedding diagrams of both the ordinary space geometry and the optical reference geometry reflecting some dynamical properties of the geodesic motion. The gravitational potential energy and the binding energy of the polytropes are determined and studied by numerical methods. The presence of a repulsive cosmological constant tends to decrease the (negative) gravitational energy, making formation of extremely compact polytropes easier by lowering the value of the parameter σ necessary to obtain an extremely compact polytrope.



Differentially Rotating Proto-Neutrons Stars

Loic Villain – *Valencia, Spain*

We present new results for evolutionary sequences of differentially rotating proto-neutrons stars, calculated by means of a relativistic spectral code. We pay special attention to the influence of differential rotation during the early evolution, discussing the possibility of constraining the rotation profile of newly born neutron stars by studying the redistribution of angular momentum during the first minute of life.

